Unit-2

Index properties of the soil:-

→ Those properties which are used in identification and classification of soil are called index properties.

Ex:- Specific Gravity, unit weight, particle size distribution, consistency, sensitivity, Activity, thixotrophy, collapsibility, atterberg limits Etc...,

→ In nature, soil occur in different forms. However soils Exhibiting similar behaviour can be put into a particular category. Different tests are done to assess the Engineering behaviour of soils.

→ Index properties are those properties which are used for the identification and classification of soils.

→ Index properties can be divided into two General types:

i) soil grain properties.

ii) soil aggregate properties.

→ The soil grain properties depend on the individual grains of soil mass whereas, soil aggregate properties depends on the soil mass as a whole i.e. soil history, mode of formation or on soil structure. Hence soil 'aggregate properties' are of great Engineering importance.

(i) soil Grain properties:-

The most important soil grain properties of soil are:

(a) Grain size distribution: by sieve and sedimentation analysis.

(b) Grain shape: Bulky, flaky and needle shaped Etc.

(ii) soil Aggregate properties:-

The various soil aggregate properties are:

(a) unconfined compressive strength (qu)

(b) consistency and atterberg's limits.

(c) sensitivity

(d) Thixotrophy and soil activity

(e) Relative density.

Type of soil	Index property
coarse soil	particle size, Grain shape and Relative density.
Fine soil	Atterberg's limit and consistency, unconfined compressive strength, thixotropy and activity.

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* particle size distribution analysis:-

→ Grain Size analysis of coarse grained soils is carried out by sieve analysis, whereas analysis of fine grained soils is by sedimentation method i.e., Either by hydrometer or pipette method.

→ Generally, Most of the soil contains both coarse candias well as fine grain constituents. Hence a combined analysis is usually carried out.

→ In combined analysis, dry soil fraction retained on seive size 4.75mm is called Gravel fraction which is subjected to coarse sieve analysis and soil fraction passing through 4.75mm sieve is further subjected to fine sieve analysis.

→ Fraction passing through 0.075mm sieve is analysed by hydrometer or pipette method.

I.S. classification

S.NO	Type of soil	particle size	Remark.
1.	Boulder	> 300mm	Not considered as soil
2.	cobbles	80mm – 300mm	
3.	Gravel	4.75mm – 80mm	
4.	Sand	0.075mm – 4.75mm	coarse Grained soil
	(4.1) coarse sand	2mm – 4.75mm	
	(4.2) Medium sand	0.425mm – 2mm	
	(4.3) Fine Sand	0.075mm – 0.425mm	
5.	Silt	0.002mm – 0.075mm	Fine Grained soil
	(5.1) coarse	0.02mm – 0.075mm	
	(5.2) Medium	0.01mm – 0.02mm	
	(5.3) Fine	0.002mm – 0.01mm	
6.	clay	< 0.002mm	

→ Soil may consist of Gravels, Sands, Silts, Clays.

→ Gravel and sand are called coarse Grains

→ Silts and clays are called fine Grains

→ If soil has fineness of 20% then it means 20% particles by weight are silts and clays (i.e. finer than 0.075mm)

particle size analysis

- coarse Grained analysis (size > 0.075mm) (or) Sieve analysis
  - coarse sieving (or) Gravel sieving (size > 4.75mm)
  - fine sieving (or) sand sieving (size 0.075 to 4.75mm)
    - Dry sieving
    - wet sieving [preferred when sand contains silts/clay]
- fine Grained Analysis (size < 0.075mm) (or) Sedimentation Analysis
  - pipette method
  - Hydrometer Method

Sieve analysis :-

> Coarse Sieving :-

→ the fraction retained on 4.75mm Sieve is called the Gravel fraction and is subjected to coarse sieve analysis.

→ Sieves are represented either by their number & either by size.

→ IS sieves have square size opening represented in mm & micrometer.

→ Sieve no. represents no. of square openings in 1 inch of length.

For Eg:- 0.075 mm size has sieve no. IS-200

→ the sieves used in coarse sieving are 80mm, 20mm, 10mm, 4.75mm (4 No. of sieves)

* the sample is shaken for 10 min in the shaking Machine and weight of soil retained on Each sieve is found.

Let, W_i = weight retained in the i^{th} sieve.

W = Total weight of soil sample taken.

$$\%\text{ weight retained on } i^{th} \text{ sieve} = \frac{W_i}{W} \times 100$$

$$\text{cumulative \% retained} = \frac{\text{Total weight of soil retain up to } i^{th} \text{ sieve}}{\text{Total weight of soil taken}} \times 100$$

$$= \sum_{i=1}^{i} \frac{W_i}{W} \times 100$$

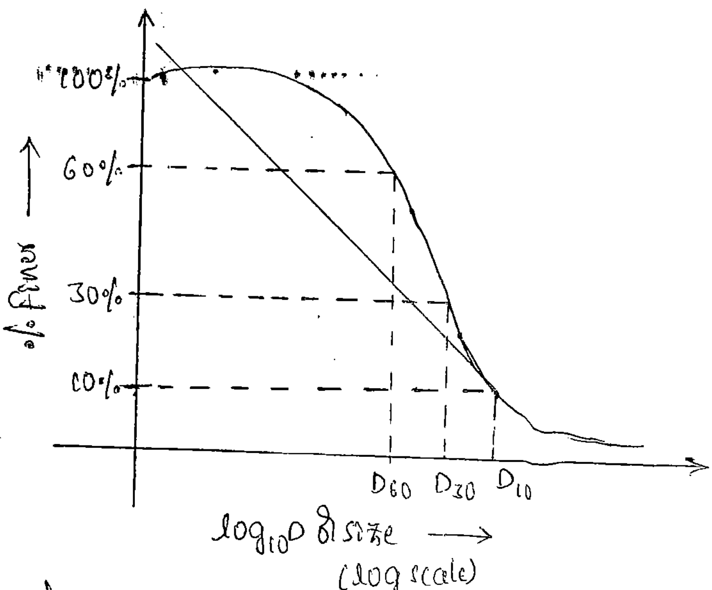
% finer than i^{th} sieve (%N) = 100 − cumulative % retained.

* Grain Size distribution curves

→ A graph is plotted between % finer and sieve size in semi-log paper.

→ Sieve size is taken on log scale on x-axis and % finer in arithmetic scale on y-axis

→ From the grain distribution curve size is computed corresponding to 60% finer, 30% finer and 10% fines are computed. they are represented as D_{60}, D_{30}, D_{10} respectively



→ D_{60} is that size below which 60% particles are finer than this size by weight.

→ D_{30} is that size below which 30% particles are finer than this size by weight.

→ D_{10} is that size below which 10% particles are finer than this size by weight. D_{10} is called Effective size.

→ D_{50} is called average size.

→ using D_{60}, D_{30} and D_{10}, following shape parameters are defined for the classification of coarse soils:

i. coefficient of uniformity:- It represents the particle size distribution and it is defined as, $C_U = \frac{D_{60}}{D_{10}}$

where,

D_{60} = that size of the particles below which 60% of particles are finer by weight.

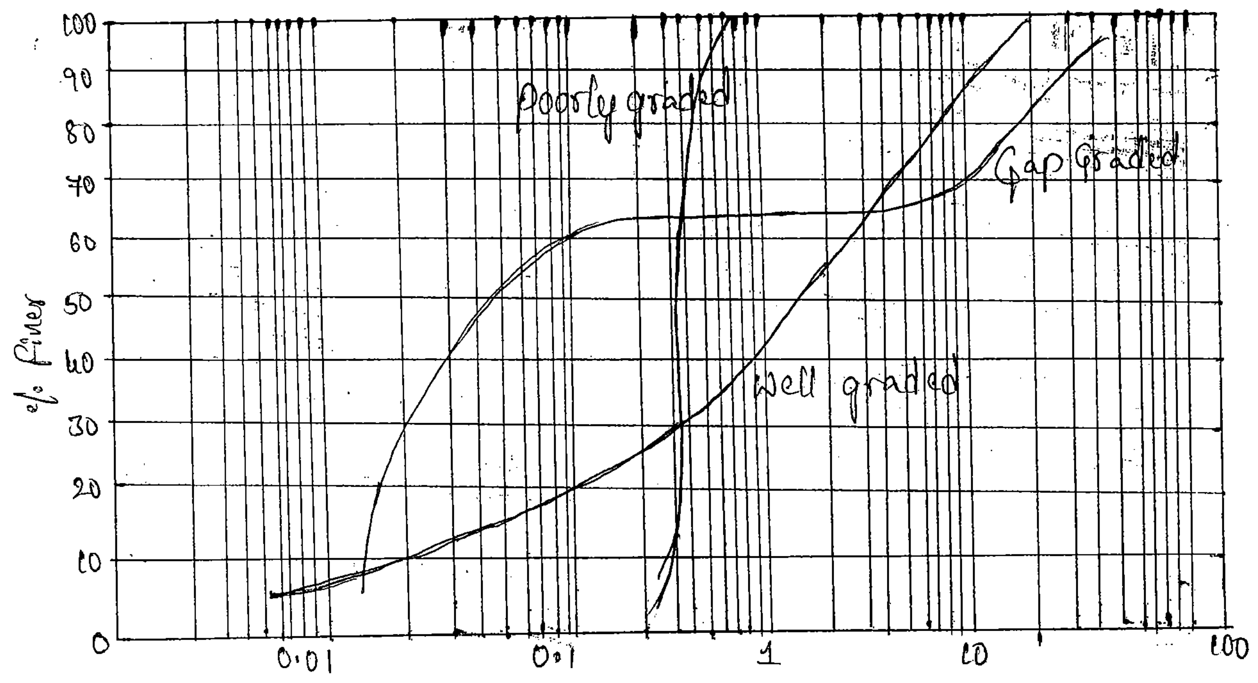
→ if $C_u = 1$; soil is perfectly uniformly graded (all are of same size)

→ for well graded Gravels $C_u > 4$

→ for well graded sands $C_u > 6$

Note:- C_u cannot be less than one(1). for gravels if C_u is 1 to 4 that gravels are poorly graded (or) uniformly graded.

→ for sands if C_u is 1 to 6 than sands are poorly graded (or) uniformly graded



Particle size (mm) - logarithmic scale.

Typical particle size distribution curve.

Coefficient of curvature :- (Cc)

— this parameter represents the shape of particles along with distribution. It is defined as

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

→ for a well graded soil Cc b/w 1 to 3 $(1 < C_c < 3)$

→ if Cc is not in the above range, then soil is poorly graded (or) uniformly graded.

* Fine Sieving (sand sieving) :-

→ Soil fraction passing through 4.75mm sieve is subjected to fine sieve analysis

→ It can be performed Either in dry state & wet state.

→ wet sieving is preferred when clay content is present in the sand. so sand is washed to remove the clay. whereas if fine soils are not mixed with sand then dry sieving may be done.

→ In fine sieving, following sieves are arranged in decreasing order as 2mm, 1mm, 600 μ-m, 425μ-m, 150μ-m and 75μm.

→ the procedure of analysis is same as coarse analysis.

Examples: From the results of a sieve analysis given below, plot a Grain-size distribution curve and then determine

(i) the Effective size

(ii) the coefficient of uniformity

(iii) the coefficient of curvature

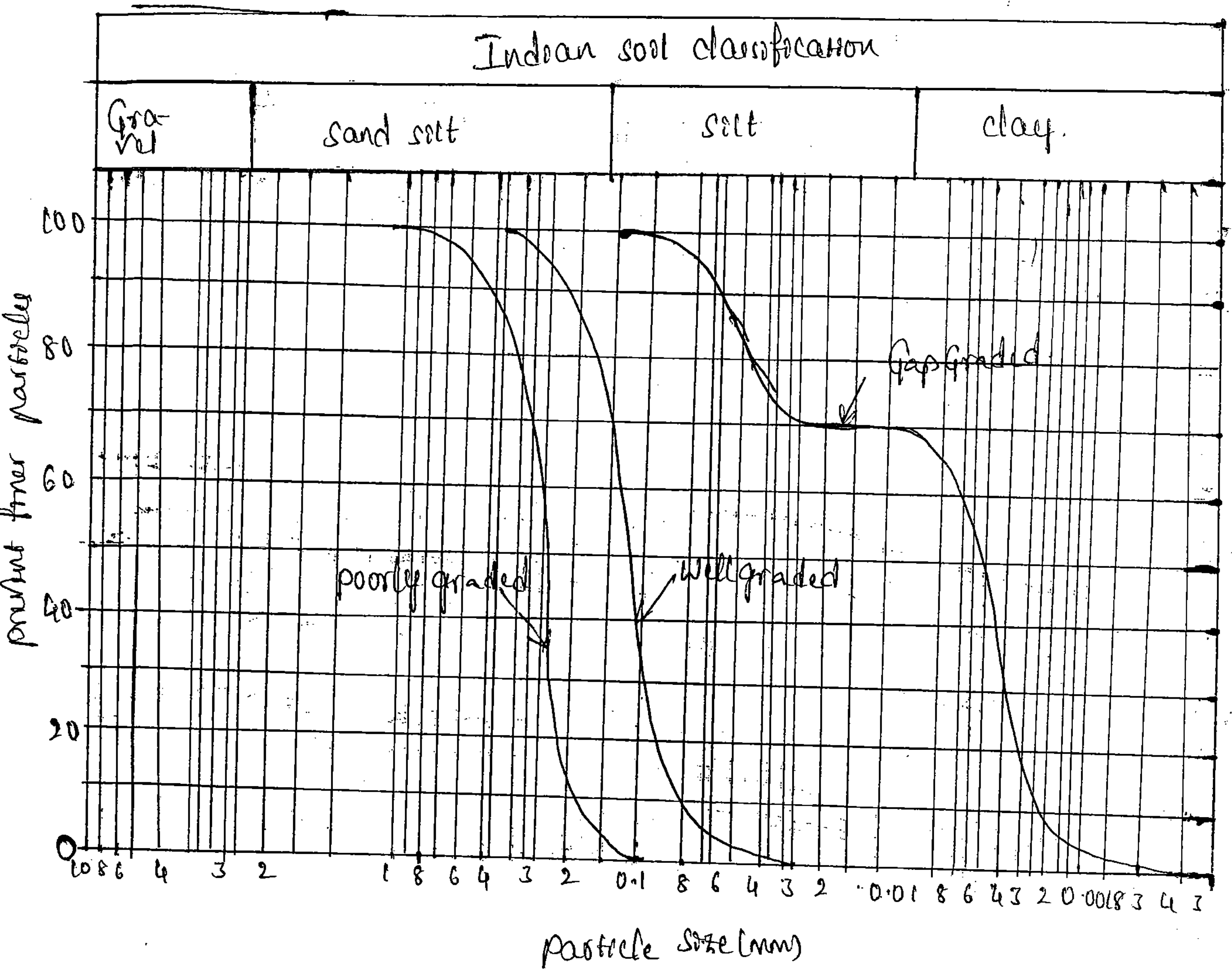
Weight of soil taken for sieve analysis was 500g.

Sieve size	weight of soil retained in Each sieve, g
4.76mm	3.8
2.40mm	32.2
1.20mm	52.8
0.60mm	38.7
0.30mm	122.5
0.15mm	15.0
0.075mm	26.4

Solution:

Sieve size (mm)	weight retained (g)	% Retained on Each sieve	% cumulative retained.	% finer %N = 100 − % cumulative Retained
4.76mm	3.8	0.76	0.76	99.24
2.40mm	32.2	6.44	7.20	92.80
1.20mm	52.8	10.56	17.76	82.24
0.60mm	38.7	7.74	25.50	74.50
0.30mm	122.5	24.50	50.00	50.00
0.15mm	159.9	31.98	81.98	18.02
0.075mm	26.4	5.28	87.26	12.74

The Grain distribution curve is plotted as shown in figure below.



From the curve,

(i) Effective size, $D_{10} = 0.07mm$

(ii) $D_{30} = 0.21mm$ and $D_{60} = 0.43mm$

$\therefore$ coefficient of uniformity, $C_u = \frac{D_{60}}{D_{10}} = \frac{0.43}{0.07} = 6.14$

(iii) coefficient of curvature, $C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.21^2}{0.43 \times 0.07} = 1.47$.

Sedimentation Analysis:-

→ Sedimentation analysis is used to determine Grain size distribution of the soil fraction passing through 75μ size.

→ It is based on the 'stoke's Law'.

→ Stoke's law:-

> If a spherical particle falls through infinitely large medium, then it will achieve a constant terminal velocity

Terminal velocity is given as

$$V_s = \frac{(\gamma_s - \gamma_w) D^2}{18\mu} = \frac{(\rho_s - \rho_w) D^2}{18\eta}$$

where,

γ_s = unit weight of settling solids / unit weight of spherical particle

γ_w = unit weight of liquid suspension(water)

D = Dia of saturating particle

μ = Dynamic viscosity coefficient / dynamic viscosity of liquid. $\frac{(N\text{-}s)}{m^2}$

η = Kinematic viscosity m^2/sec.

V_s = Settling velocity (or) terminal velocity.

Note:- μ is function of temperature and at 20°c for water μ is 0.01 poise.

→ at 20°c

$\boxed{V_s \approx 0.9 D^2}$ $V_s \rightarrow m/sec$

$D \rightarrow mm$

→ at 27°c μ is 0.0085 poise

$\boxed{V_s = 1.07 D^2}$

* Limitations of stokes law :-

→ the analysis is based on the assumption that the falling particle is spherical. but in soils, the finer particles are never truly spherical

→ Stoke's law considers the velocity of free fall of a single sphere in a liquid. of infinite Extension, whereas the grain size analysis is usually carried out in a glass jar in which the Extent of liquid is limited.

→ the fine grains of soil carry charges on their surface and have a tendency for, for floc formation. if the tendency of floc formation is not prevented, the diameter measured will be the diameter of the floc and not of the individual.

→ particles should be Discrete.

→ Note :- clay particles are flaky and discrete. Means no change in size and shape while settling.

→ the fluid is infinetly large so that no resistance of Boundary.

→ the flow around the particle is laminar.

the laminar flow can be maintained the particle size is smaller than 0.2 mm and Greater than 0.0002mm

NOTE :-

→ stoke's law is applicable for spheres of diameter between 0.2mm and 0.0002mm.

→ Spheres of diameter larger than 0.2mm falling through water causes turbulence, whereas for spheres with diameter less than 0.0002mm, Brownian Motion takes place and the velocity of settlement is too small for accurate Measurement.

procedure of sedimentation Analysis:-

A dry soil sample of 12 to 30 grams is added in the water to form 500ml suspension for pipette Method and 1000ml suspension for Hydrometer Method

→ the suspension is stirred and allowed for settling with the time settlement of particles occurs and to find percentage fines observations are taken at regular intervals.

→ the observations May be taken Either using pipette Method (or) using Hydrometer Method. Both are Based on principle of stoke's law.

→ Before taking observations following two treatments are required.

1. pre treatment to the soil:-

→ Treatment given before making of soil suspension to remove organic Matter and calcium compounds.

for organic matter – oxidizing agent is used (e.g. H_2O_2)

for calcium compounds – Acids are used (e.g. HCl)

2. post – treatment to the soil:-

→ It is done after preparation of soil suspension to break the flocs that are formed due to presence of surface Electric charges.

→ the dispersing agents (deflocculating agent) used are. Sodium hexameta phosphate or calgon, sodium oxalate Etc.

→ the analysis is carried out by the hydrometer or pipette Method. the principle of the test is (both) same in both Methods. the difference lies only in the Method of Making observations.

According to IS – 2720 it is recommended that 33grams of Sodium Hexa Metaphosphate and 7grams of sodium carbonate should be mixed in one litre of water and 25ml of this water should be added in soil Suspension.

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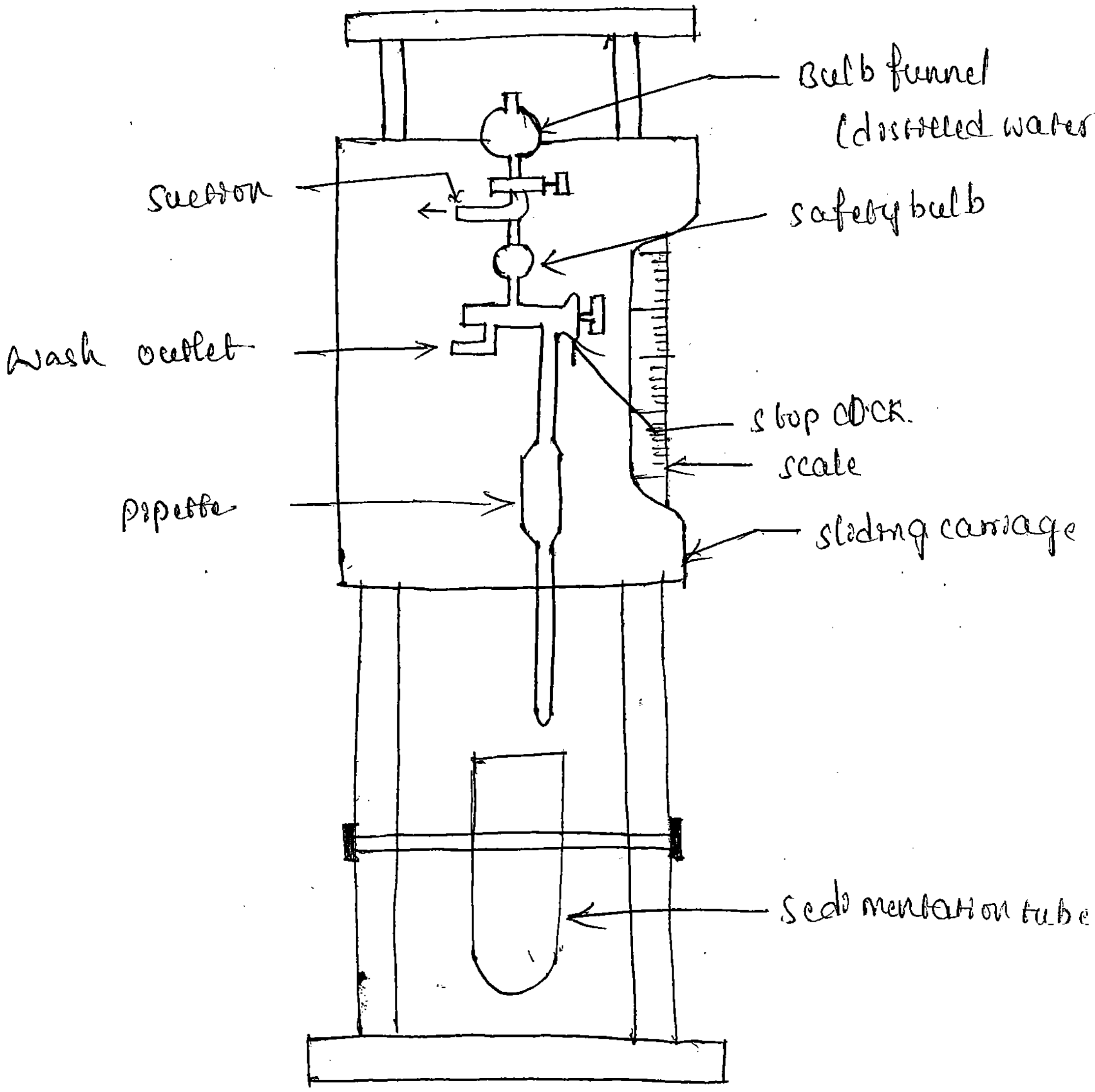
$(33+7) = \frac{40}{1000} \times 25 = \underline{1gm}$

Deflocculating agent is added in soil sample.

* <u>pipette Method</u>:-

→ In this Method 10ml of sample is collected from a specified depth of <u>10cm</u> from the soil suspension at different time intervals.

→ This 10ml sample is put in a container and is dried in oven to get dry unit weight / dry density.



→ let M_D be the Mass of dried sample obtained from pipette Volume (V_p=10ml)

Hence, Mass per unit volume of dried sample.

$$= \frac{M_d}{\text{Volume of pipe}(V_p)} = \frac{M_d}{10ml}$$

let M is the total mass of dry soil which is used to prepare the suspension having total volume of V.

(then mass per unit volu)

→ If dispersing agent added in the total volume V, let mass of dispersing agent is M'.

then mass per unit weight of dispersing agent is $= \frac{M'}{V}$

→ the Mass per unit volume of soil solids at any time interval is given by

$$= \frac{M_d}{V_p} - \frac{M'}{V}$$

→ Initial Dry mass per unit volume = M/V

→ the percentage finer is given by

$$\% N = \frac{\text{dry mass per unit volume.}}{\text{Initial dry mass per unit volume}} \times 100$$

$$\% N = \frac{\frac{M_d}{V_p} - \frac{M'}{V}}{\frac{M}{V}} \times 100$$

→ the diameter of falling particle at any instance of time is given by the stoke's law

$$V_s = \frac{He}{t} = \frac{\gamma_s - \gamma_w}{18\mu} D^2$$

$$D = \sqrt{\frac{18\mu}{\gamma_s - \gamma_w} \frac{He}{t}}$$

$$D = \sqrt{\frac{18\mu}{\gamma_s - \gamma_w}} \times \sqrt{\frac{H_e}{t}}$$

$$\therefore \boxed{D = K\sqrt{\frac{H_e}{t}}}$$

where,

K is a constant depending upon solid and liquid particles.

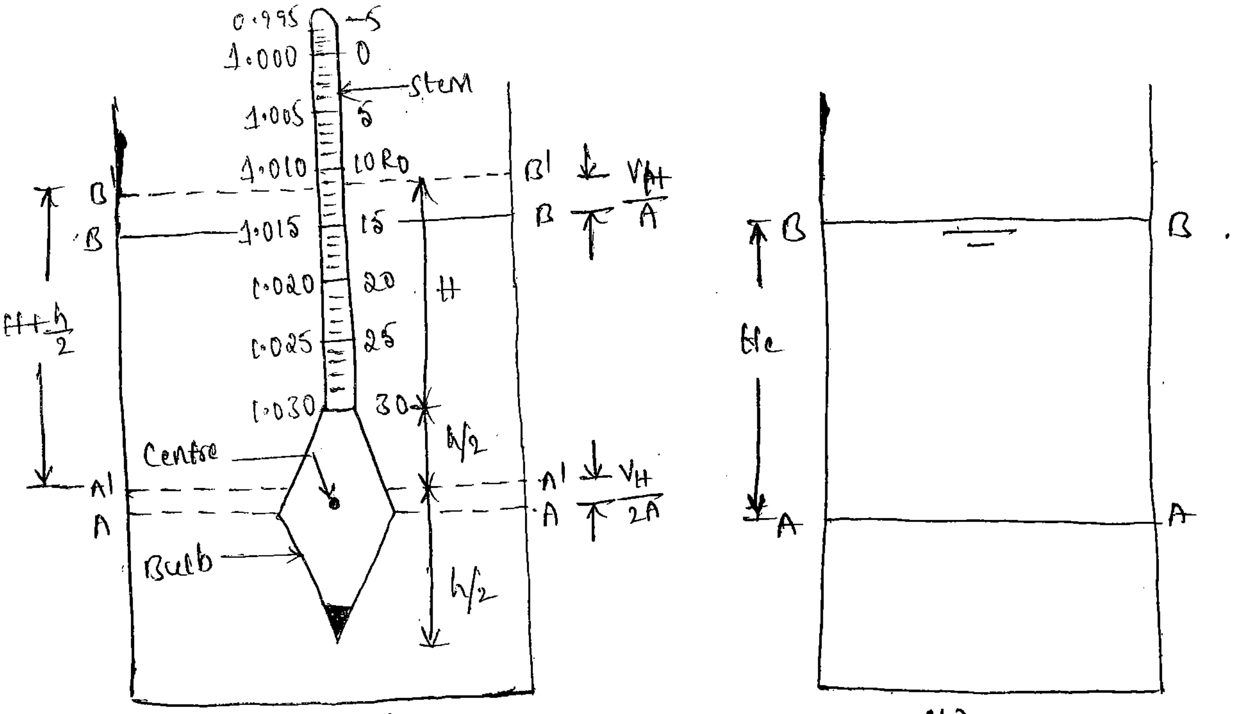
H_e = Effective depth of observation (10cm) / Effective depth through which particle settles

→ observation are taken at regular intervals, a graph is plotted between % finer (%N) and diameter of particle.

% finer in y-axis, dia in log scale in x-axis.

→ From the particle distribution graph D_{60}, D_{30}, D_{10} are obtained which can be used to find C_u and C_c.

Hydrometer Method:-



(a) (b)

→ It is also based on stoke's law.

→ Hydrometer is a device used to measure specific Gravity of liquids

→ In this method, the weight of solid present at any time is calculated directly by reading the density of soil suspension

→ calibration of Hydrometer:- It involves Establishing a relation between the hydrometer Reading R_H and Effective depth (H_e).

the Effective depth is the distance from the surface of the soil suspension to the level at which the density of soil suspension is being measured.

> Effective depth is calculated as

$$H_e = H_1 + \frac{1}{2}\left(h - \frac{V_H}{A_j}\right)$$

where, H_1 = distance (cm) between any hydrometer reading and neck.

h = length of hydrometer bulb

V_H = Volume of hydrometer bulb

A_j = area of the cross section of the jar

> Reading of hydrometer is related to specific Gravity & density of soil suspension as:

$$G_l \text{ (or) } G_{ss} = 1 + \frac{R_H}{1000}$$

Thus a reading of $R_H = 25$ means, $G_{ss} = 1.025$

and a reading of $R_H = -25$ means, $G_{ss} = 0.975$

> the % finer in terms of Hydrometer reading is defined as

$$\% N = \frac{G}{G-1} \rho_w \cdot \left(\frac{V}{W}\right)\left(\frac{R_H}{10}\right)\%$$

where, $G = G_{ss}$ = sp. Gravity of soil solids

R_H = final corrected reading of Hydrometer.

V = Total volume of soil suspension.

W = weight of soil mass dissolved in g

$\rho_w = 1$ gm/cc.

* Hydrometer corrections :-

i) Meniscus correction (C_m) :-

→ the actual reading could be taken at bottom but due to turbidity Top reading is recorded.

→ Hydrometer reading is always corresponding to the upper level to Meniscus.

→ therefore, Meniscus correction is always positive.

ii) Temperature correction (C_t) :-

→ Hydrometers are Generally calibrated at 27°c.

→ If the test temperature is above the standard (27°c) the correction is added and if below, it is subtracted.

iii) Dispersing/Deflocculating agent correction (C_d):-

→ the correction due to rise in specific Gravity of the suspension on account of the addition of the deflocculating agent is called dispersing agent correction (C_d).

- Apparent Density increases by the addition of dispersion agent.

→ therefore, 'C_d' should be always negative.

→ the corrected hydrometer Reading is given by

$$R_{HC} = R_H + C$$

where, $C = C_m \pm C_t - C_d$

$$\therefore \boxed{R_{HC} = R_H + C_m \pm C_t - C_d}$$

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* Consistency of clays (Atterberg's limits) / Consistency limits:-

→ Consistency refers to the degree of deformation which may recorded in a soil due to change in water content.

→ Consistency represents / is a measure of relative ease with which a soil can be deformed.

→ In practice, consistency is a property associated only with fine grained soils, Especially clays

→ Consistency of clays is related to the water content.

→ Depending on percentage water content, four stages of consistency are used to describe the state of clayey soil:

1. Solid state
2. Semi solid state.
3. plastic state
4. Liquid state.

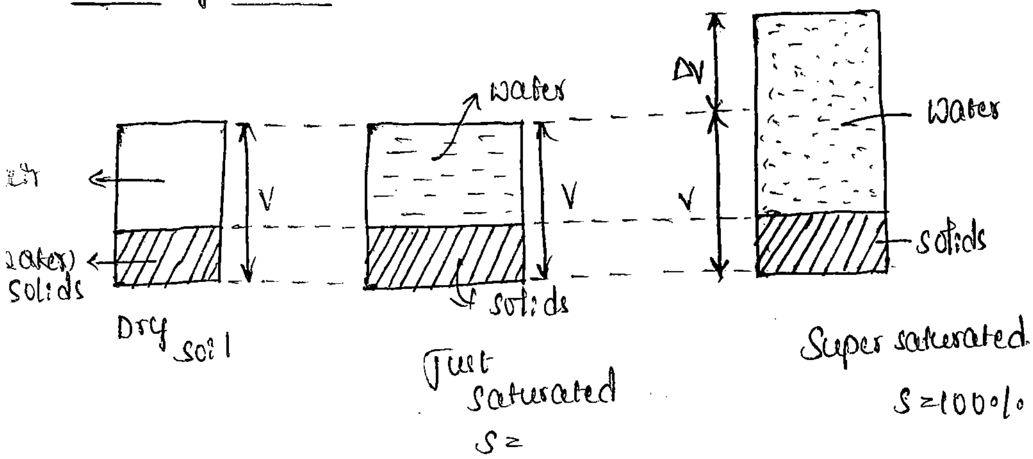
→ the water content between any two states at which consistency changes is called consistency limit.

(or)

→ the boundary between any two states is called consistency limit. they are also known as Atterberg limits after Swedish scientist Atterberg, who first demonstrated the significance of these limits. Hence there are three consistency limits.

1. liquid limit (consistency changes from plastic state to liquid state)
2. plastic limit (consistency changes from semi solid state to plastic state)
3. Shrinkage limit (consistency changes from solid state to semi solid state)

Consistency curves :-



where, V_d = volume of dry soil mass
= volume of soil at shrinkage limit.
V_p = volume of soil at plastic limit.
V_L = volume of soil at liquid limit.
w_L = liquid limit (S = 100%)
w_p = plastic limit (S = 100%)
w_s = shrinkage limit.

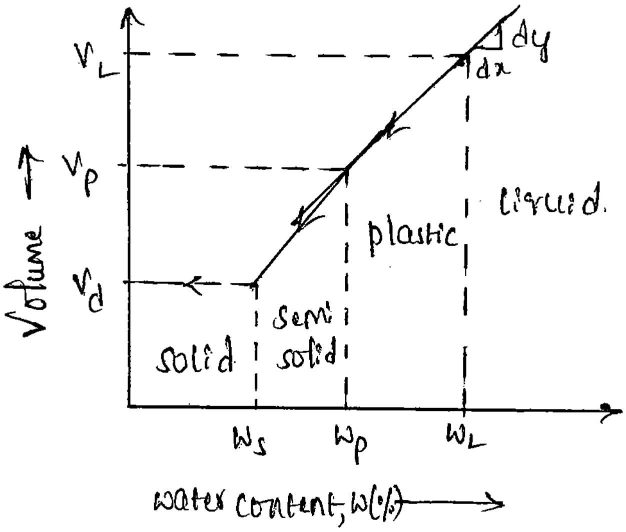


fig: states of clayey soil and consistency limits.

Slope, $\tan\theta = \frac{dy}{dx}$ = constant.

$$\tan\theta = \frac{V_L - V_p}{w_L - w_p} = \frac{V_p - V_d}{w_p - w_s} = \frac{V_L - V_d}{w_L - w_s} = \text{constant}.$$

→ For change in water content corresponding to change in degree of saturation from 0 to 100%, there is no change in total volume of soil. But for water content increasing greater than shrinkage limit (S = 100%), then with change in water content total volume of soil also changes.

→ At shrinkage limit all the pores of soil are just filled by water. Hence degree of saturation (S) is 100%

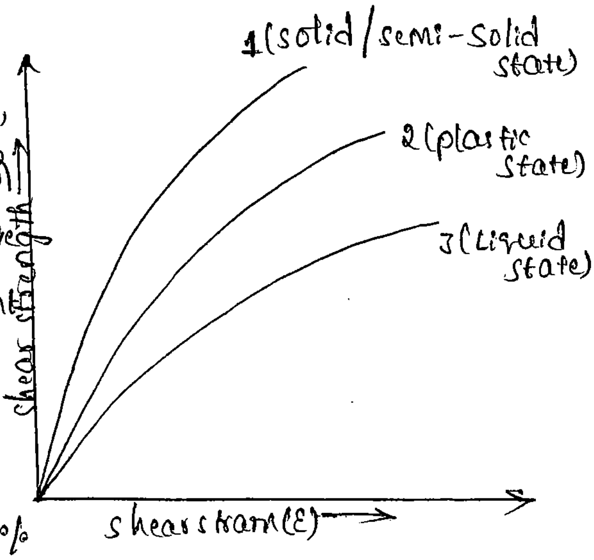


fig: shear strength behaviour at different soil states.

→ Naturally existing soils has water content between w_L and w_p

→ On increase in water content shear strength of soil decreases.

→ At liquid limit, all soils have negligible and equal shear strength

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* Liquid Limit:-

→ It is that minimum water content at which soil has tendency to flow. At liquid limit, consistency of soil changes from plastic state to liquid state.

→ At liquid limit all soil have nearly negligible shear strength of 2.7 KN/m² approximately

→ If liquid limit of a soil is Greater then such soils are more compressible (swelling and shrinking)

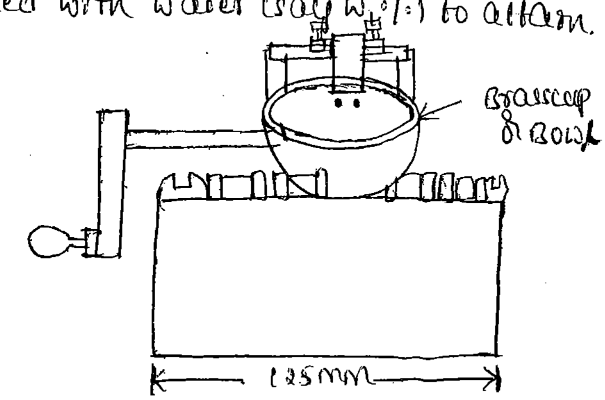
Ex:- Black soils.

* Methods to determine Liquid Limit:-

i) casagrande's apparatus
ii) one point method
iii) static cone penetration method.

* casagrande's apparatus:-

→ About 120g oven dried soil is taken and mixed with water (say w_1%) to attain putty like consistency.

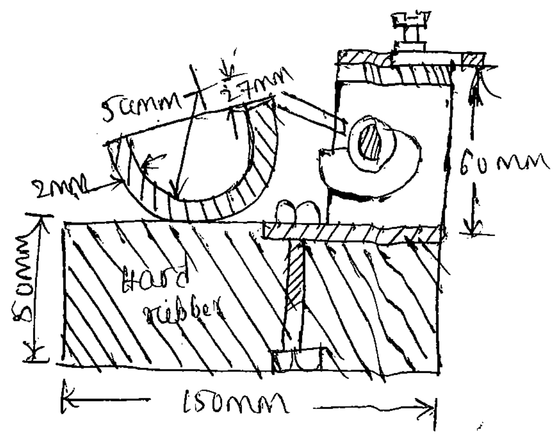


→ paste is placed inside casagrande apparatus cup and levelled.

→ A groove of 2mm size is cut on the soil sample with casagrande tool (or) ASTM tool which are trapezoidal and apparatus is given blows over a rubber pad and no of blows required to close the 2mm grove is noted as N_1.

→ Now same soil is mixed with water content w_2 and no. of blows required to close the 2mm groove is noted say N_2.

→ same process is repeated with different water content.



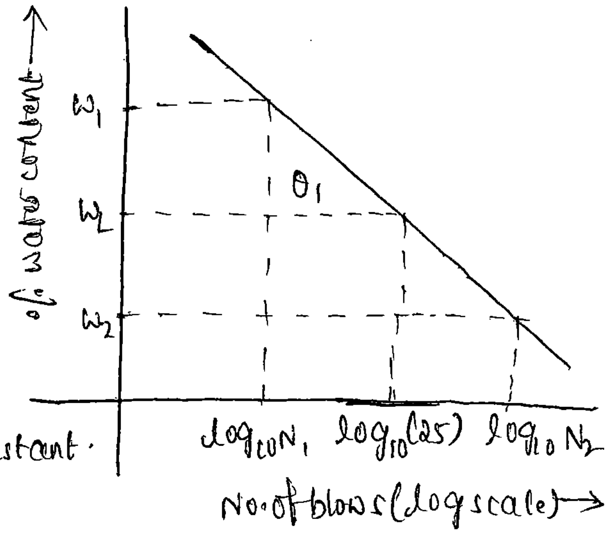
Standard liquid limit test apparatus

→ A graph is plotted between % water content and No. of Blows in semi log scale

→ the above curve is called flow curve and the slope of above curve is called flow index

$I_f = \tan\theta$

$= \dfrac{w_1 - w_2}{\log_{10}N_2 - \log_{10}N_1} = \dfrac{w_1 - w_2}{\log_{10}\left(\frac{N_2}{N_1}\right)} =$ constant.



In this apparatus the height of free fall of cup is assumed to 1cm and cup is allowed to fall freely on a hard rubber base. if rubber is used softer than the standard Hardness. then liquid limit will increase.

If soil has Greater flow index, it means that the rate of loss of shear strength with increase in water content is high.

Note:- the compressibility of soil directly depends on liquid limits. Greater the liquid limit, Greater is the compressibility of the soil.

e.g. for soil x, $w_L = 42\%$

for soil y, $w_L = 56\%$

soil y is more compressible than soil x

→ clay have more liquid limit than silt.

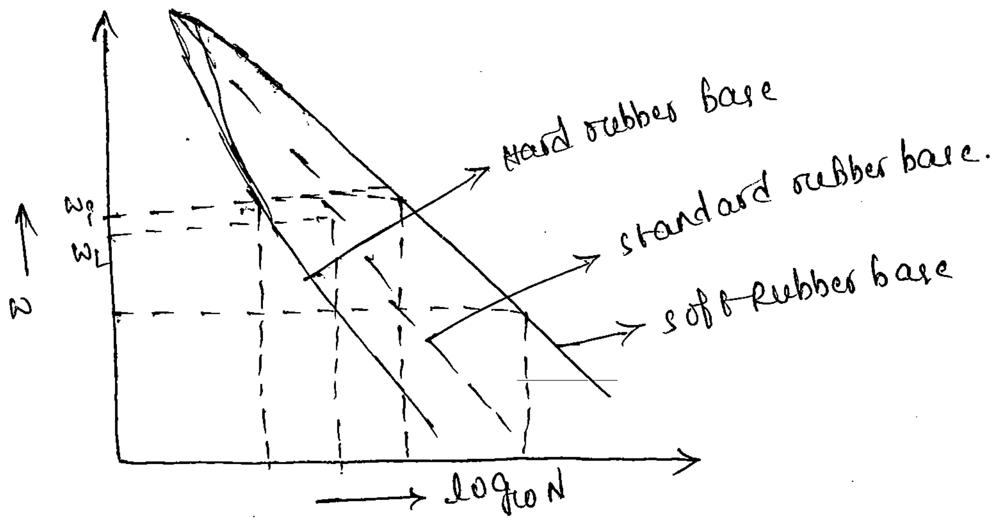
Special cases:-

if $N_1 = 10$ and $N_2 = 100$ then $I_f = \dfrac{w_1 - w_2}{\log_{10} N_2/N_1}$

$\therefore \boxed{I_f = w_1 - w_2}$

Note:-

→ If rubber base is harder than standard Hardness then flow index will increase (flow curve will be steeper)



→ If rubber base is soft liquid limit increases

→ If rubber base is Hard liquid limit will decreases.

→ the liquid limit is Equal to that water content for which Groove will be closed in 25 blows

ASTM Tool		Casagrande Tool
Base width :- 2mm	————	2mm
Top width :- 13.5mm	————	11mm
height :- 10mm	————	8mm

* plastic limit :- (w_p)

→ the water content at which soil sample changes from semi-solid to plastic state is known as plastic limit.

→ plastic limit is also defined as the water content at which soil would just begin to crumble when rolled into a thread of approximately 3mm diameter.

→ clays have high plastic limit and liquid limit.

but LL > PL

→ Fine soils have Greater plasticity. at plastic limit soil changes from semi solid state to plastic state.

→ coarse grained soil like sand and gravel have less liquid limit and plastic limit Generally.

→ the difference between liquid limit and plastic limit is known as plastic Index (or) plasticity Index (I_p)

$$I_p = W_L - W_p$$

→ the plastic Index represents ~~that range~~ of water content in which soil is in plastic state.

→ the plastic limit depends upon amount and type of clay mineral in soil. Hence clay containing fine soils have more plastic limit.

Type of soil	Liquid Limit	plastic limit.	$I_p = W_L - W_p$
Gravel	<10%	<10%	Zero
Sand	10-15%	10-15%	Zero
Alluvial soil (clay)	40-60%	20-40%	20-40%
Black soil	400-500%	200-250%	200-250%
Alluvial soil (sands)	10-50%	10-15%	10-15%

Notes:

→ If organic matter is mixed with soil then L.L and P.L both increases but increase in LL > increase in PL.

→ If sand is mixed in clays then L.L and P.L both reduces but decrease in LL > decrease in PL

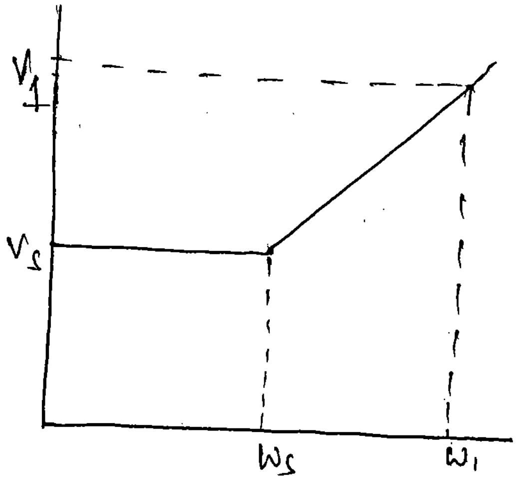
Note:-

If soil sample one (1) has plasticity Index I_{p_1} and its percentage is x_1 and if it is mixed with soil sample two (2) have a plasticity Index I_{p_2} and its proportion is x_2 then after mixing plasticity index of mixed soil will be

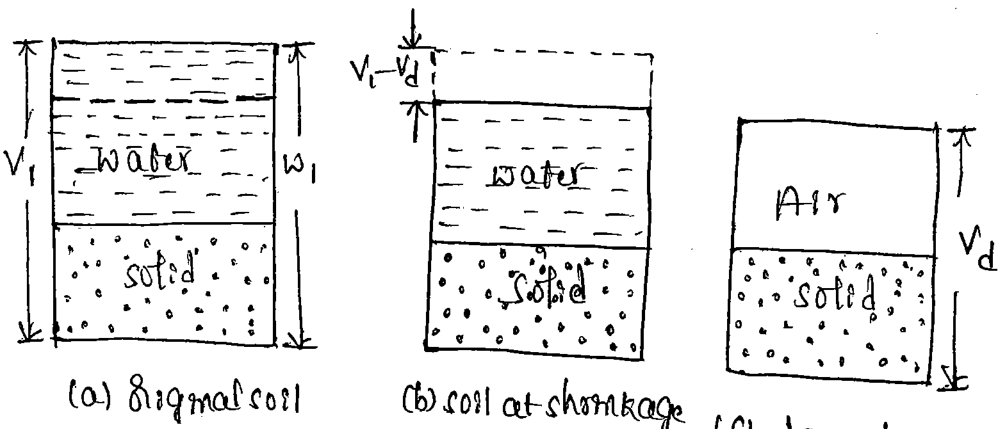
$$I_p = \frac{I_{p_1}x_1 + I_{p_2}x_2}{x_1+x_2}$$

* Shrinkage limit (w_s):-

→ A state when the decrease in moisture content leads to solid state, no change in volume of soil mass is observed. the consistency of soil changes from semi to solid state. the boundary water content is called shrinkage limit.



→ Shrinkage limit is the smallest value of water content at which soil mass is completely saturated. It means that below shrinkage limit soil is partially saturated



(a) original soil (b) soil at shrinkage limit (c) dry soil

Fig:- Determination of shrinkage limit.

i) $S \cdot e = w \cdot G$

at shrinkage limit $S = 1$, $w = w_s$

$$\therefore \boxed{w_s = e/G}$$

ii) Let W_1 ($W_1 > W_s$) is the water content at which volume (is equal to Dry volume of it) of soil is V_1

Let W_s is shrinkage limit at which volume is equal to Dry volume of soil

$W_s = W_1 -$ water content between W_1 & W_s

$$= W_1 - \frac{(V_1 - V_d)\gamma_w}{W_s}$$

$\therefore W_s =$ wt of dry soil $= W_d$

(or)

$$w_s = \frac{W_w}{W_s} = \frac{(W_1 - W_s) - (V_1 - V_d)\gamma_w}{W_d} = \frac{(W_1 - W_s)}{W_d} - \frac{(V_1 - V_d)\gamma_w}{W_d}$$

$$w_s = w_1 - \left(\frac{V_1 - V_d}{W_d}\right)\gamma_w$$

where, V_1 = original volume of soil

V_d = dry volume of soil

W_1 = original weight of soil

$W_d = W_s$ = dry weight of soil (solids)

w_1 = natural water content.

iii) Shrinkage limit is co-related with the specific Gravity of soil solids which can be found using following relations

$$G = \frac{1}{\frac{\gamma_w}{\gamma_d} - \frac{w_s}{100}}$$

where, γ_w = unit weight of water

γ_d = dry unit weight of soil

w_s = % shrinkage limit.

* shrinkage ratio (R):-

→ It is defined as the ratio of a given volume change in a soil, Expressed as a percentage of the dry volume to the corresponding change in water content above the shrinkage limit.

$$SR \text{ (or) } R = \frac{\left(\frac{V_1 - V_2}{V_d}\right) \times 100}{w_1 - w_2}$$

where, V_1 = volume of soil mass at water content w_1%

V_2 = volume of soil mass at water content w_2%

V_d = volume of dry soil mass.

- Special case:- At shrinkage limit,

$w_2 = w_s$ and $V_2 = V_d$.

$$R = \frac{\left(\frac{V_1 - V_d}{V_d}\right) \times 100}{w_1 - w_s} = \frac{V_s}{w_1 - w_s} \times 100$$

$$\Rightarrow V_s = \frac{SR \times (w_1 - w_s)}{100}$$

↓ volume of shrinkage

- shrinkage ratio can also be defined as,

$$R = \frac{\gamma_d}{\gamma_w}$$

* **Volumetric shrinkage**: It is the percentage loss in volume of soil on drying

$$V_s = \frac{V_1 - V_d}{V_d} \times 100$$

(or)

$$V_s = R(w_1 - w_s)$$

* **Degree of shrinkage**: It is the percentage loss in volume of soil on drying corresponding to initial volume.

$$D.O.S = \frac{V_1 - V_d}{V_1} \times 100$$

where, V_1 – initial volume of soil sample

V_d – Dry volume of soil sample

Degree of shrinkage	<5%	5–10%	10–15%	>15%
plasticity	Good	Medium	poor	Very poor.

* **Linear shrinkage**: It refers to decrease in one dimension of soil expressed as % of initial dimension.

$$L_s = \left[1 - \left(\frac{100}{100+V_s}\right)^{1/3}\right] \times 100$$

V_s = volumetric shrinkage

* **Stress-strain curve for different consistency states**:

(a) $I_c < 0$ (b) $0 < I_c < 1$ (c) $I_c > 1$

* **Activity (Ac):-** It is relative to shrinkage & swelling property of a soil due to the moisture variation

→ the behaviour of clay with change in water content is influenced by the presence, magnitude and type of clay minerals,

According to skempton, Activity is defined as

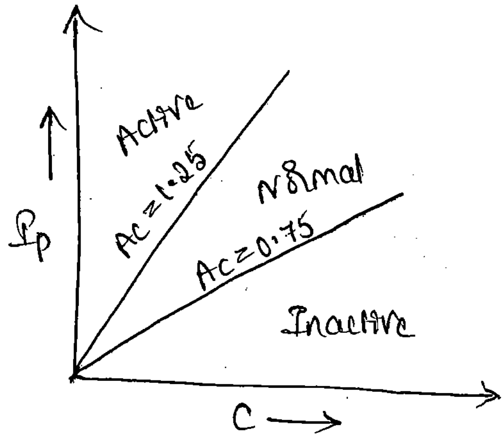
$$A_c = \frac{\% I_p}{\% C}$$

where, I_p = plasticity Index

$\% C$ = % of particles which are of clay size i.e. smaller than 2μ

→ classification of clays, based on Activity

Activity (Ac)	consistency
<0.75	Inactive
0.75<Ac<1.25	normal
Ac>1.25	Active.



- Higher activity means soil is more compressible and represents more change in volume due to moisture variation, hence high active soils are not preferred for foundation works.

- **Activity of clay minerals:-**

Type of Minerals	Activity (Ac)
Kaolinite.	0.38
Illite.	0.90
Montmorillonite	7.2

Note: Black cotton soil and bentonite soils has high content of montmorillonite.

* Plasticity Index :-

→ The more plastic soil means more volume change on loading usually coarse grained soils are non-plastic gravels, sands where as clays are highly plastic.

→ Plasticity Index represents the range of consistency in which soil is in plastic state and is given by

$$\boxed{I_p = W_L - W_P}$$

Plasticity Index	Plasticity of soil.
0	non-plastic
1-5%	slightly plastic
5-10%	low plastic
10-20%	Medium plastic.
20-40%	High plastic.
>40	Very high plastic

→ Plasticity Index of mixed soils:-

> Let x_1% of soil 'A' having plasticity Index I_{p1}, is mixed with x_2% of soil 'B' having plasticity Index I_{p2}. then, the I_p of mixed soil will be.

$$I_p = \frac{x_1 I_{p_1} + x_2 I_{p_2}}{x_1 + x_2}$$

* Shrinkage limit:-

→ It represents semi-solid state of consistency. and is defined as difference of plastic limit and shrinkage limit

$$\boxed{I_s = W_p - W_s}$$

Where, W_p = water content at plastic limit

W_s = water content at shrinkage limit

* Consistency Index / Relative consistency (I_C) :-

→ It is defined as a ratio of the difference between the liquid limit and the natural water content of the soil to the plasticity index.

$$I_C = \frac{w_L - w}{I_P} = \frac{w_L - w}{w_L - w_p}$$

where, w_p = water content at PL

w_L = water content at LL

w = Natural water content.

% I_C	% water content	consistency
$I_C < 0$	$w > w_L$	soil is in liquid state
$0 < I_C < 1$	$w_p < w < w_L$	soil is in plastic state
$I_C > 1$	$w < w_p$	soil is in solid / semi solid.

* Liquidity Index (I_L) :-

→ It is defined as the ratio of the difference between the natural water content of a soil and its plastic limit to its plasticity index

$$I_L = \frac{w - w_p}{I_P} = \frac{w - w_p}{w_L - w_p}$$

% I_L	% water content	consistency
$I_L < 0$	$w < w_L$	solid / semi solid state
$0 < I_L < 1$	$w_p < w < w_L$	plastic state.
$I_L >$	$w > w_L$	Liquid state

Note:- sum of consistency Index and liquidity index is always unity

$$\therefore I_C + I_L = 1.$$

* Toughness index (I_t):-

→ I_t is defined as the ratio of plasticity index to the flow index.

$$I_t = \frac{I_p}{I_f}$$

→ It gives an idea about the shear strength of a soil at plastic limit. For the same value of plasticity index, two soils exhibit different toughness based on flow index.

→ For most of the soil: $0 < I_t < 3$

→ when $I_t < 1$, the soil is easily crushed (friable) at the plastic limit.

* Sensitivity (S_t):-

→ Consistency of a clay sample is altered even at the same water content on its remoulding. This change in consistency & loss of strength takes place due to the following:

(i) Due to permanent destruction of soil solids on remoulding.

(ii) Due to change in orientation of the water molecules in the adsorbed layer of soil solids.

→ Sensitivity is defined as the ratio of the unconfined compressive strength of an undisturbed specimen of the soil to the unconfined compressive strength of a specimen of the same soil after remoulding at unaltered water content

$$S_t = \frac{(q_u)\ \text{undisturbed}}{(q_u)\ \text{remoulded}}$$

where, q_u = unconfined compressive strength

→ Sensitivity represents degree of disturbance achieved on remoulding.

* soil classification based on sensitivity:-

Sensitivity	% water content	Consistency
1–4	Normal	Gravel, coarse sand
4–8	sensitive	Sand.
8–15	Extrasensitive	Flocculent structure soil
>15	Quick	Fineclay.

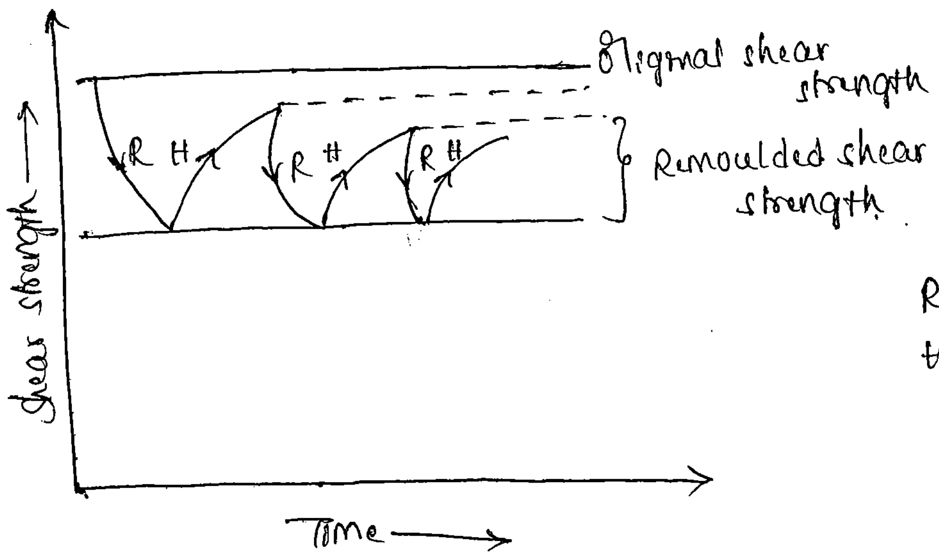
* Thixotropy:-

→ It is that property of soil due to which loss in shear strength due to remoulding at unaltered moisture content may be regained

→ the loss in shear strength due to remoulding may be by following two reasons:-

- Disturbance in Orientation of Molecules
- permanent Breaking of Bond b/w molecules

→ the loss of a strength caused by disturbance in Orientation of molecules is recoverable where as loss caused by breaking bond is not Recoverable.



R ⇒ Remoulding
H ⇒ Hardening

→ cohesive soils have greater thixotropy than cohesionless soils.

[illegible] larger the thixotropic hardening

* unconfined compressive strength (q_u):-

→ Defined as the load per unit area at which unconfined cylindrical specimen of standard dimension fails in a simple compression test.

$$q_u = 2C_u$$

where, C_u = cohesion of pure clay

q_u is related to consistency of clays.

q_u (kN/m²)	<25	25-50	50-100	100-200	200-400	>400
consistency	Very soft	soft	Medium	stiff	Very stiff	Hard

* collapsibility :-

→ Soils which show large decrease in volume with increase in water content at same pressure are termed as collapsible soil. such soils are found in deserts and are highly perforated

Eg:- Loess

→ collapsibility of the soil is analysed in terms of a parameter termed as collapse potential.

→ collapse potential is defined as the ratio of change in volume of the soil with increase in water content to its original volume.

→ collapse potential can be determined by performing a simple plate load test in the field.

collapse potential, $C_p = \frac{\Delta V}{V_0} = \frac{\Delta H}{H_0} = \frac{\Delta e}{1+e_0}$

$$C_p = \frac{\Delta V}{V_0} = \frac{\Delta H}{H_0} = \frac{\Delta e}{1+e_0}$$

where, H_0 = initial depth/thickness of soil deposit before change in water content.

ΔH = change in depth due to change in water content.

e_0 = initial void ratio

Δe = change in void ratio.

collapsible potential %		Effect on structure.
0 – 1	–	No trouble
1 – 5	–	Moderate.
5 – 10	–	Trouble.
10 – 20	–	severe trouble
> 20	–	Very severe trouble

* Methods to differentiate various type of soils :-

→ To differentiate organic and inorganic clay.

find liquid limit of ovendried soil sample and.

find liquid limit of airdried soil sample

> If soil is organic clay then liquid limit of oven dried sample is less than 0.7 times liquid limit of air dried sample.

> on ovendry liquid limit and plastic limit of organic clay reduces. However the Reduction in plastic limit is less than reduction in liquid limit.

→ To differentiate between clay and silt in field the following terms can be used.

i) Dispersion test :- Take a spoon of dried soil sample and mixed in a glass of water if soil settles down in 10 to 15 minutes then it is silt. But if it forms turbit suspension then the soil is clay.

ii) Dilatance test:-

→ Take a moist/wet sample of soil place on the palm and shake. if surface of soil become shining that is water comes on the surface, soil is silt surface remains dull, then soil is clay.

iii) Dry strength test:-

→ A spherical balls are prepared and placed for air dry having size of 3mm. after air dry balls are pressed between fingers if soil crumbles (or) pressed then it is silt but if it is hard then it is clay.

iv) Toughness test:-

→ If threads of 3mm dia are rolled b/w two palms then cracks will appear if soil silt. But if soil is clay it can be rolled in threads.

Examples problems:-

* A soil has liquid limit 40% and plastic limit of 25%. Determine the toughness index of soil if flow index is 20%.

(a) 1 (b) 0.25

(c) 0.5 (d) 0.75 ✓

A.

$I_p = W_L - W_p$

$I_p = 40 - 25 = 15\%$

Toughness index, $I_t = \frac{I_p}{I_f}$

$I_t = \frac{15}{20} = 0.75$

Hence option(d) is correct.

* A sample of the soil has following properties:

liquid limit = 45%

plastic limit = 25%

shrinkage limit = 17%

Natural moisture content = 30%

the consistency (of) index of the soil is.

A. plasticity Index, $I_P = W_L - W_P$

$I_P = 45 - 25 = 20\%$

consistency Index, $I_C = \frac{W_L - W}{I_P} = \frac{45-30}{20} = \frac{15}{20}$

* A soil has following properties:

Liquid limit = 35

plastic limit = 20

Natural moisture content = 25%

Find plasticity index, liquidity index and shrinkage index.

A. plasticity index, $I_P = W_L - W_P$

$I_P = 35 - 20 = 15\%$

Liquidity Index, $I_L = \frac{W - W_P}{I_P}$

$I_L = \frac{25-20}{15} = 33\%$

Shrinkage Index, $I_S = W_P - W_S$

$I_S = 20 - 10 = 10\%$

* Atterberg's limit — soil A — soil B

Atterberg's limit	soil A	soil B
Liquid limit	40	0
plastic limit	15	0

soil A and soil B are mixed to prepare a clayey soil of plasticity index of 12, the percentage of sand in the mix should be.

A.

$$I_{P1} = W_L - W_P = 40 - 15 = 25$$

$$I_{P2} = 0$$

Let percentage of B to be mixed is x

$\therefore$ $$x_2 = x \text{ and } x_1 = 100 - x$$

$$I_{p\,mix} = \frac{x_1 I_{p1} + x_2 I_{p2}}{x_1 + x_2}$$

$$12 = \frac{(100 - x) \times 25 + x \times 0}{100}$$

$$1200 = 2500 - 25x$$

$$\boxed{x = 52\%}$$

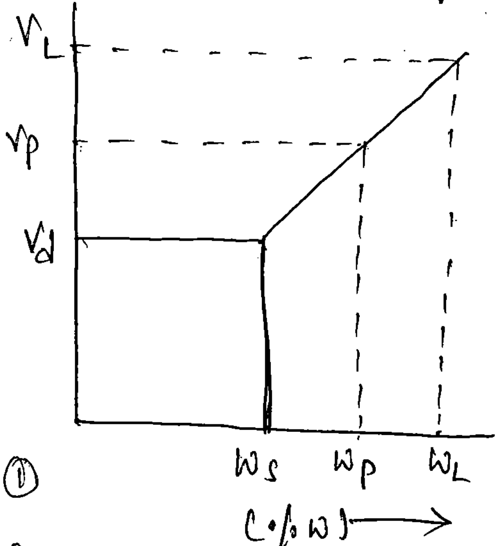
* the liquid limit and plastic limit of sample are 60% and 30% respectively. the percentage of the soil fraction with grain size finer than 0.002mm is 20. the activity ratio of the soil sample is

A.

$$A_C = \frac{I_P}{\%C} = \frac{W_L - W_P}{\%C}$$

$$A_C = \frac{60 - 30}{20} = 1.5$$

* the plastic limit of a soil is 24% and its plasticity index is 8%. when the soil is dried from its state at plastic limit, the volume change is 26% of its volume at plastic limit. the corresponding volume change from the liquid limit to dry state is 35% of its volume at liquid limit. Determine the shrinkage limit and the shrinkage ratio.



A. Given,

$w_p = 0.24$

$I_p = 0.08$

$I_p = w_L - w_p = 0.08$

$w_L = 0.08 + 0.24 = 0.32$

$V_p - V_d = 0.26 V_p$ (given) — (1)

$V_p - V_d = 0.35 V_L$ (given) — (2)

substracting (ii) from (i), we get

$$V_p - V_L = 0.26 V_p - 0.35 V_L$$

$$0.26 V_p = 0.65 V_L$$

$$V_L = 1.138 V_p \quad — (3)$$

From geometry, $\frac{dy}{dx}$ = slope = constant

$$\frac{w_p - w_s}{V_p - V_d} = \frac{w_L - w_p}{V_L - V_p}$$

$$\frac{0.24 - w_s}{0.26 V_p} = \frac{0.32 - 0.24}{1.138 V_p - V_p} \Rightarrow \frac{0.24 - w_s}{0.26 \cancel{V_p}} = \frac{0.08}{\cancel{V_p}(1.138 - 1)}$$

$$\frac{0.24 - w_s}{0.26} = \frac{0.08}{0.138}$$

$$0.24 - w_s = 0.15$$

$$w_s = 0.09 \; 9\%$$

→ shrinkage ratio, $R = \frac{V_1 - V_2}{V_d} \times 100 \Big/ w_1 - w_2$

$$= \frac{\frac{V_1 - V_2}{V_d} \times 100}{w_1 - w_2} = \frac{\frac{V_L - V_p}{V_d} \times 100}{w_L - w_p}$$

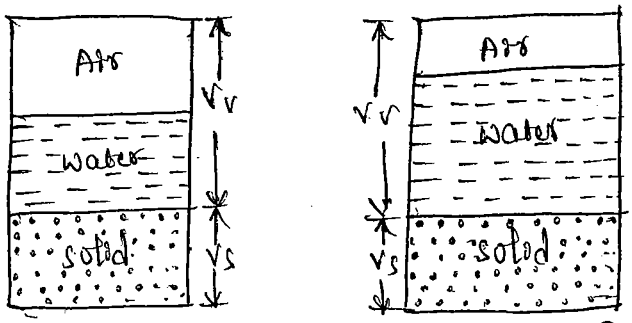
$$R = \frac{1.38 V_p - V_p}{0.74 V_p \times (0.32 - 0.24)}$$

$$R = \frac{0.138}{0.74 \times 0.08} = 2.33$$

* Examples:

1. A clayey soil has saturated moisture content of 15.8%. the specific gravity is 2.72. Its saturation percentage is 70.8%. the soil is allowed to absorb water. After some time, the saturation increased to 90.8%. Find the water content of the soil in the later case.

A. $G = 2.72$, $S = 70.8$, $w = 15.8\%$



(a) case I (b) case II

In case I,

void ratio, $e = \frac{wG}{S} = \frac{0.158 \times 2.72}{0.708} = 0.607$

since degree of saturation is within $0 < S < 100\%$. Hence volume of void remain same

$$e_1 = e_2$$

$$w = \frac{0.908 \times 0.607}{\quad} = 0.2036 \times 20.36\%$$

2. A cohesive soils yields maximum dry density of 1.8 g/cc at an optimum moisture content of 16%. If $G_s = 2.65$, then find the degree of saturation. Also determine the maximum dry density which can be possible to achieved.

A. Given, $\rho_{d,max} = 1.8\, g/cc$

$w = 16\%$ or 0.16

$G = 2.65$

We know, $\rho_d = \frac{G\rho_w}{1+e}$

$\therefore \quad e = \frac{2.65 \times 1}{1.8} - 1 = 0.472$

Also, $S.e = wG$

$S = \frac{wG}{e} = \frac{0.16 \times 2.65}{0.472} = 0.89$ or 89%.

theoretical maximum dry density will be achieved when all the air present in the voids Escaped out. i.e. all voids are just filled by water only.

$\therefore$ For condition of theoretical maximum dry density,

$S = 100\%$ or 1

$S.e = w.G$

$e = \frac{w.G}{S} = \frac{0.16 \times 2.65}{1} = 0.424$

$\therefore$ Theoretical maximum density, $\rho_{d\,max} = \frac{G\rho_w}{1+e} = \frac{2.65 \times 1}{1+0.424} = 1.86\, g/cc$.

3. You are a project Engineer on a large dam project that has a volume of 800,000 m³ of selected fill, compacted such that the final void ratio in the dam is 0.80. The project manager delegates to you the important decision of buying the Earth fill from one of the three suppliers. Which one of the three suppliers is the most economical and how much will you save.

Supplier A sells fill at 5 Rs/m³ with e = 1.50

Supplier B sells fill at 10 Rs/m³ with e = 0.20

Supplier C sells fill at 12 Rs/m³ with e = 1.00

A. Without considering void ratio, it would appear that supplier A is cheaper than B by 5 Rs/m³.

Volume of solid needed for dam site, $V_s = \frac{V}{1+e} = \frac{8,00,000}{1+0.80} = 444,444 m^3$

Volume of soil required to be taken out from suppliers,

Supplier A, $V_A = V_s(1+e) = 4444,44\ (1+1.50) = 1,111,110 M^3$

Supplier B, $V_B = V_s(1+e) = 444,444\ (1+0.2) = 544,442 M^3$

Supplier C, $V_C = V_s(1+e) = 444,444\ (1+1.6) = 1155,555\ M^3$

Cost of bills,

Supplier A, $A = 1,111,110 \times 5 = 5,555,550$ Rs/-

Supplier B, $B = 533,332 \times 10 = 5,333,320$ Rs/-

Supplier C, $C = 1155,555 \times 12 = 13,866,660$ Rs/-

Therefore supplier B is more Economical, and we save Rs/-

$= 5,555,550 - 5,333,320$

$= 222,230.$

4. The fines fraction of a soil to be used for a Highway near Hapur was subjected to a hydrometer analysis be placing 25g of dry soil in 1000ml solution of Water ($\mu = 0.01$ poise at 20°C). The specific Gravity of the solid was 2.65

(a) Estimate the maximum diameter D of the particle found at a depth of 5cm after a sedimentation of 4 hour has elapsed, if the solution's concentration has reduced to 2g/lit at the level.

(b) What % of the sample would have a diameter smaller than D?

A. Given, $W_1 = 25g$, $V = 1000ml$ or $1000cc$.

$t = 4hrs = 14,400sec$, $H_e = 5cm$, $\mu = 0.01 poise = 0.001\ Ns/m^2$

(a) using stoke's law,

$$V = \frac{\gamma_w (G-1)}{18\mu} D^2 = \frac{He}{t}$$

$$\therefore \quad D = \sqrt{\frac{18\mu He}{\gamma_w (G-1)t}} = \sqrt{\frac{18 \times 0.001 \times 5 \times 10^{-2}}{9.81 \times (2.65-1) \times 14400}}$$

$$= 6.2 \times 10^{-5} m = 0.062 mm$$

(b) concentration of solution $= \frac{2g}{l} = 2g$ soil solids in 1 litre.

unit weight of solution after 4 hrs,

$$\gamma = \frac{\text{weight of solution}}{\text{volume of solution}} = \frac{W_s + W_w}{V} = \frac{W_s + (V - V_s)\gamma_w}{V}$$

$$\gamma = \frac{2g + \left[V - \frac{W_s}{G\gamma_w}\right] \times \gamma_w}{V} \qquad \left[\because G = \frac{W_s}{V_s \gamma_w}\right]$$

$$\gamma = \frac{2 + \left[1000 - \frac{2}{2.65 \times 1}\right] \times 1}{1000} = 1.001 \, g/cc$$

But $\quad \gamma = 1 + \frac{R_H}{1000}$

$\therefore \quad R_H = 1.245$

% finer than particle of size 0.0615 m

$$\% = \frac{G}{G-1} \gamma_w \left(\frac{V}{W_1}\right)\left(\frac{R_H}{10}\right)\%$$

$$= \frac{2.65}{2.65-1} \times 1 \times 1 \left(\frac{100}{25}\right) \times \left(\frac{1.245}{10}\right) = 8\%$$

* problems on Hydrometers

→ the corrected hydrometer reading in 1000ml of soil suspension, 60 minute after commencement of Sediment is 20. the Effective depth from the calibrations is 165mm. If the particle specific Gravity is 2.74 and the viscosity of water is 0.01poise, calculate.

i) the smallest particle size which would have settled during this interval of 60 minutes

ii) % of particle finer than this size.

the total weight of the soil sample taken was 48grams.

A. Given, $V = 1000ml$

$t = 60min$ (or) $3600sec$

$\mu = 0.01$ poise $= 0.01 \times 10^{-1}$ N-s/m2

$He = 165mm$

(i) $$\frac{He}{t} = \frac{(G-1)\gamma_w D^2}{18\mu}$$

$$D = \sqrt{\frac{18\mu He}{(G-1)\gamma_w t}} = \sqrt{\frac{18 \times 0.01 \times 10^{-1} \times 165 \times 10^{-3}}{(2.71-1) \times 981 \times 3600}}$$

$= 2.198m \times 10^{-5}$ (or) $0.022mm$

ii) percentage finer than particle of size D is given by,

$$\%N = \frac{G}{(G-1)\rho_w} \times \left(\frac{V}{W}\right) \times \left(\frac{R_H}{L_0}\right)\%$$

where, G = sp.gravity of solid.

V = volume of soil sample = 1000ml (or) 1000cc.

W = weight of dry soil used to make suspension = 48g

R_H = corrected Hydrometer reading = 20

$$\%N = \frac{2.74}{(2.74-1)} \times 1 \times \left(\frac{1000}{48}\right) \times \left(\frac{20}{10}\right)\% = 65.61\%$$

→ In a hydrometer analysis, 45gm of soil is mixed with distilled water to make 1200ml suspension. After 45 sec the reading of hydrometer is 1.015, the depth of suspension below the reading is found to be 140mm. the dimension of hydrometer are:

volume of hydrometer = 75cc

the internal area of Jar of hydrometer = 60cm²

Assuming $\rho_w = 1g/cc$, $\mu = 0.001 N-s/m^2$ and $G_s = 2.7$.

Findout the coordinate of the point on the Grain size plot.

A. Given, $V_H = 75cc$, $A = 60cm^2$

$$H_e = H_1 + \frac{1}{2}\left(h - \frac{V_H}{A_j}\right) = \left(H + \frac{1}{2}h\right) - \frac{V_H}{2A_j}$$

Here $\left(H + \frac{1}{2}h\right)$ = Depth of suspension below the hydrometer reading

= 140 mm (or) 14cm

$$H_e = 14 - \frac{75}{2 \times 60} = 13.375CM$$

By stoke's law, we have $D = \sqrt{\frac{18\mu H_e}{(G-1)\gamma_w t}} = \sqrt{\frac{18 \times 0.001 \times 13.375 \times 10^{-2}}{(2.7-1)981 \times 45}}$

percentage finer (%N) is given by,

$$\% N = \frac{G}{G-1} \rho_w \left(\frac{V}{W}\right)\left(\frac{R_H}{10}\right)\%$$

Since reading of hydrometer is ~~1.015~~ 1.015 which is density of suspension at the time of observation,

$$\therefore \quad 1.015 = 1 + \frac{R_H}{1000}$$

$$\frac{R_H}{1000} = 0.015$$

Hence $\%N = \frac{2.7}{(2.7-1)} \times 1 \times \left(\frac{1200}{45}\right) \times \left(\frac{15}{10}\right)\% = 63.52\%$

thus the coordinate of the point on the grain size curve is (0.179mm, 63.52)

*** Example problems:**

1. An oven dried soil sample has volume 225c/c as in dry mass 390 grams. if specific Gravity is 2.72. determine the void ratio & shrinkage limit. what will be the water content which will fully saturate the sample & will result an increase in volume 8% of dry volume.

A.

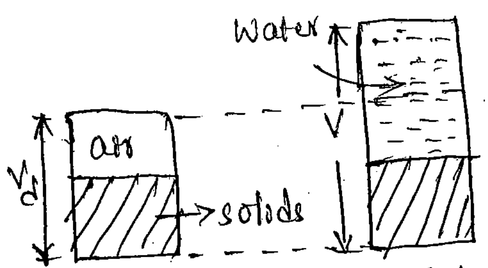
$V_d = 225cc$

$M_d = 390grams$

$G = 2.72$

$e = ?$

$w_s = ?$



$e = \ ; S = 0 \leftarrow$ Dry soil

saturated (super saturated)

$e' = \ ; S' = 1$

$V' = 1.08 V_d$

$= 1.08 \times 225 = 243cc$

$$G = \frac{1}{\frac{\gamma_w}{\gamma_d} - \frac{w_s}{100}}$$

$$= \frac{1}{\frac{\rho_w}{\rho_d} - \frac{w_s}{100}}$$

$$\frac{\rho_w}{\rho_d} - \frac{w_s}{100} = \frac{1}{G}$$

$$\Rightarrow w_s = \left(\frac{\rho_w}{\rho_d} - \frac{1}{G}\right) \times 100$$

$$\Rightarrow w_s = 21.03\%$$

Dry density $\rho_d = \frac{M_d}{V_d}$

$$= \frac{390}{225} = 1.73$$

$$\rho_d = \frac{G \cdot \rho_w}{1+e}$$

$$1+e = \frac{G \cdot \rho_w}{\rho_d}$$

$$e = \frac{G \cdot \rho_w}{\rho_d} - 1$$

$$= \frac{2.72 \times 1}{1.73} - 1$$

$$e = 0.572$$

volume of soil in dry state = volume of solid after saturation

$V_s = V'$

$$\Rightarrow \frac{V_d}{1+e} = \frac{V'}{1+e} \Rightarrow \frac{1+e'}{1+e} = \frac{V'}{V}$$

$$e' = 0.6977.$$

$$s'e' = w'G$$

$$1 \times 0.6977 = w' \times 2.72$$

$$\boxed{w' = 25.65\%}$$

2. the Mass specific gravity of a fully saturated soil (clay) with water content 40% is 1.88 when sample is oven dried. the mass specific gravity reduces to 1.74. compute the shrinkage limit and the specific Gravity of solids?

A. $G_M = 1.88$; $w = 40\%$

$$(G_M)_{\text{ovendried}} = 1.74$$

Saturated soil Mass:

$$G_M = \frac{\gamma_{sat}}{\gamma_w} = 1.88.$$

$$\frac{\gamma_{sat}}{\gamma_w} = \left(\frac{G+e}{1+e}\right)\frac{\gamma_w}{\gamma_w} = 1.88.$$

$$\frac{\gamma_{sat}}{\gamma_w} = \left(\frac{G+e}{1+e}\right)\frac{\gamma_w}{\gamma_w} = 1.88.$$

$$\frac{G+e}{1+e} = 1.88.$$

, at full saturated conditions $s=1$

$$s.e = w.G$$

$$1.e = 0.4G$$

$$e = 0.4G \rightarrow (1)$$

from Equation (1)

$$\frac{G+0.4G}{1+0.4G} = 1.88$$

$\frac{\gamma_d}{\gamma_w} = 1.74$ = Mass sp. gravity after Drying.

$$G = \frac{1}{\frac{\gamma_w}{\gamma_d} - \frac{w_s}{100}}$$

$$w_s = \left(\frac{\gamma_w}{\gamma_d} - \frac{1}{G}\right) \times 100$$

$$= \left(\frac{1}{1.74} - \frac{1}{2.9}\right) \times 100$$

$$\boxed{w_s = 22.98\%}$$

Note:- Since water content in saturated soil (40%) is greater than shrinkage limit (22.98%)

→ ∴ Initially the soil is in super saturated stage

→ ∴ on drying it's volume and void ratio will change.

3. A mass of soil is coated with thin layer of paraffin wax. the mass of soil and wax is 690.6 grams and mass of soil alone is 683 grams. when wax coated sample is immersed in water it displaces 350 ml of water. the sp. gravity of soil solids is 2.73 that of wax is 0.89. find void ratio and degree of saturation of soil? Given that [$w_{soil\,mass} = 17\%$]

A. Mass of soil M = 683 grams

Mass of soil + Mass of wax = 690.6 grams

Mass of wax = 690.6 − 683
= 7.6 grams

Sp. gr. of wax = 0.89.

Density of wax $\rho_{wax} = 0.89 \times \rho_w$

$= 0.89 \times 1$

$= 0.89\ gm/cc$

Volume of wax $= V_{wax} = \frac{M_{wax}}{\rho_{wax}} = \frac{7.6}{0.89}$

$= 8.54\ cc$

Volume of water $=$ volume of soil $+$ volume of wax

$= 350\ cc$

Volume of soil $= V = 350 -$ volume of wax

$= 350 - 8.54 = 341.46\ cc$

Bulk density of soil $= \frac{M}{V} = \frac{683}{341.46} = 2\ gm/cc$

Dry density $= \frac{\rho_d}{1+w} = \frac{2}{1+0.17} = 1.709\ gm/cc$

$\rho_d = \frac{G \cdot \rho_w}{1+e} \Rightarrow 1+e = \frac{G \cdot \rho_w}{\rho_d}$

$e = \frac{G \cdot \rho_w}{\rho_d} - 1 = \frac{2.73 \times 1}{1.709} - 1$

$= 0.597$

$Se = wG$

$\Rightarrow S = \frac{wG}{e} = \frac{0.17 \times 2.73}{0.597} = 0.773$

$\simeq 77.3\%$.

* Engineering classification of soils:-

→ Several classification systems were developed by various organizations for their specific purpose.

→ Some important classification system are as follows:-

- > classification based on grain size
- > Textural classification
- > unified soil classification system (USCS)
- > American association of state highway and transport officials (AASHTO) system.
- > Indian standard soil classification system (ISSCS)

* Textural classification. (More suitable for coarse grained soils):-

→ In this system, soil fractions as per the US Bureau of soils and chemistry system are used.

→ According to this classification

Gravel : > 1.00 mm

Sand : 0.05 mm – 1.00 mm

Silt : 0.005 mm – 0.05 mm

Clay : < 0.005 mm.

→ A triangular chart has been developed using grain size distribution. First of all grain size distribution of the soil is found and % fractions are determined with the well known percentages of sand, silt and clay, a point is located in the triangular chart as shown in figure, specified term designated in the chart for the area where the point falls is taken as classification of the soil.

Clay (size)	Silt (size)	Sand				Fine Gravel	Gravel
		Very fine	fine	Medium	Coarse		
0.005	0.05	0.10	0.25	0.5	1.0	2.0	

→ This classification system widely used in Agriculture and highway Engineering

→ This classification depends on the grain size distribution only.

* The unified soil classification system (USCS):-

→ this system (USCS), originally developed by A. Casagrande.

→ According to USCS, the coarse grained soils are classified on the basis of their grain size distribution and fine grained soils (whose behaviour is controlled by plasticity) on the basis of their plasticity characteristics.

→ soils are classified into four major groups:-

> coarse grained
> fine grained
> organic soils
> peat.

Note:- USCS is adopted by IS classifications with slight modifications.

* 'AASHTO' soil classification system:-

→ According to AASHTO system, the soils are classified into eight groups:-

> A-1 through A-7 with an additional group A-8 for peat or muck.

→ This system includes several sub groups. soil within each group are evaluated according to the Group index calculated from empirical formula.

$$\text{Group index, } GI = 0.2a + 0.005ac + 0.01bd.$$

where, a = that part of the percentage passing the 75μ sieve greater than 35 and not exceeding 75.

b = that part of the percent passing the 75μ sieve greater than 15 and not exceeding 55.

c = that part of the liquid limit greater than 40 and not greater than 60

d = that part of plasticity index greater than 10 and not exceeding 30.

* Indian standard soil classification system (ISSCS):-

→ The Indian soil classification (IS: 1498, 1970) is basically the same as that of USCS with the slight modification that the fine grained soil have been subdivided into three subgroup of low, medium and high compressibility as against only two in the USCS.

> In this system, coarse grain soils are classified on the basis of grain size distribution and fine soils on the basis of plasticity.

> Broadly soils are divided into four major groups.

1. coarse grained soils : Gravel (G) and sand (s)
2. fine grained soils : silt (s) and clay (c)
3. organic soils (O)
4. peat (pt).

I.S. classification (grain size distribution)

Soils								
Boulder (mm)	cobble (mm)	coarse grained soil					fine grained sand	
		Gravel		sand			silt (mm)	clay (mm)
		coarse (mm)	fine (mm)	coarse (mm)	medium (mm)	fine (mm)		
>300	300-80	20-80	4.75-20	2-4.75	0.425-2.0	0.075-0.425	0.002-0.075	<0.002

Basic soil components

Sl No	Soil component	symbol
	Boulders	None
	Cobbles	None
1)	coarse-grained soils Gravel sand	 G S
2)	fine-grained soils silt clay	 M C
3)	organic matter	O
4)	peat	pt

* Classification of coarse Grained soils:-

→ classification of coarse grained soil is done on the following basis

1) particle size

2) Gradation characteristics i.e. C_u and C_c

3) % fineness (% fraction which pass through 75µ sieve)

→ coarse grained soil are those having 50% or more retained on the 0.075mm sieve. (+75 micron).

→ Further, the coarse grained soils are designated as gravel(G) if 50% or more of the coarse fraction is retained on the 4.75mm sieve; otherwise, they are designated as sand (S).

→ prefix and suffix of ISSCS:

Soil type	prefix	subgroup	suffix
Gravel	G	well graded	W
sand	S	poorly graded	P
silt	M	silty	M
clay	C	clayey	C
organic	O	$w_L < 35\%$	L
organic	O	$35 < w_L < 50$	I
peat	pt	$50 < w_L$	H

Note:-

→ well graded soils (W) have wide range of particle size where as poorly graded soil (P) has most of the particle about same size i.e. Either Excess or a deficiency of certain particle sizes.

→ To check, whether a soil is well graded or poorly graded, grain size distribution curve is plotted and coefficient of uniformity (Cu) and coefficient of curvature (Cc) are found.

* on the basis of % fineness, coarse grained soils can be further classified as:

Case-1 : when fineness is less than 5% by weight.

Gravels: More than 50% of coarse fraction retained on 4.75mm sieve.

(i) GW ⟹ well graded gravel.

$C_u > 4, 1 \le C_c \le 3$ and fineness < 5%

(ii) GP ⟹ poorly graded gravel

Above values of C_u and C_c are not satisfied.

Sand:- More than 50% of coarse fraction pass through 4.75mm sieve.

i) SW ⟹ well graded sand.

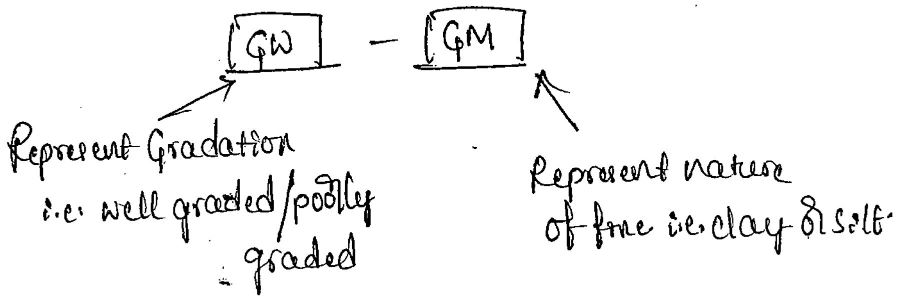
$C_u > 6, 1 \le C_c \le 3$ and fineness < 5%

ii) SP ⟹ poorly graded sand.

Above values of C_u and C_c are not satisfied.

Case-2:- when fineness is between 5-12%

This is known as borderline case and dual symbols are used. First part of dual symbol represent gradation and second part represents nature of fines i.e., clay or silt.



Gravel:-

(i) GW-GC ⟹ well graded gravel containing clay as fine

$C_u > 4, 1 \le C_c \le 3$ clay fraction > silt fraction

(ii) GW-GM ⟹ well graded gravel containing silt as fine

$C_u > 4, 1 \le C_c \le 3$

silt fraction > clay fraction

(iii) GP-GC ⟹ poorly graded gravel containing clay as fine

Above values of C_u and C_c are not satisfied

clay fraction > silt fraction.

iii) GW-GM ⇒ well graded gravel containing silt as fine.

$C_u > 4$, $1 \le C_c \le 3$

silt fraction > clay fraction.

iv) GP-GM ⇒ poorly graded gravel containing silt as fine.

above values of C_u and C_c are not satisfied

silt fraction > clay fraction.

Sand:- More than 50% of coarse fraction pass through 4.75mm sieve.

(i) SW-SC ⇒ well graded sand containing clay as fine.

$C_u > 6$; $1 \le C_c \le 3$

clay fraction > silt fraction.

(ii) SP-SC ⇒ poorly graded sand containing clay as fine.

Values of C_u and C_c are not satisfied

clay fraction > silt fraction.

(iii) SW-SM ⇒ well graded sand containing silt as fine.

$C_u > 6$, $1 \le C_c \le 3$

silt fraction > clay fraction.

iv) SP-SM ⇒ poorly graded sand containing silt as fine

Values of C_u and C_c are not satisfied.

silt fraction > clay fraction.

Case-3:- when fineness is more than 12%

In this case soil is classified according to I.S. plasticity chart (%Ip)

Gravels:-

(i) GC ⇒ clayey gravel

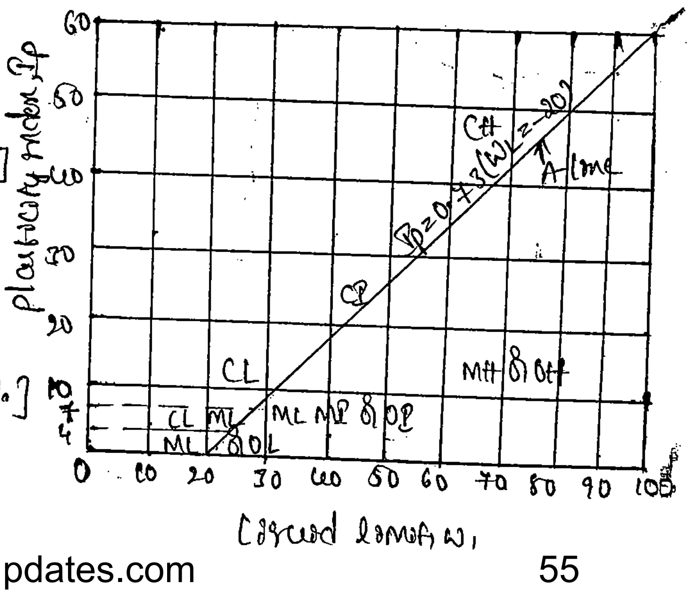
% fineness > 12 and $I_p > 7\%$

clay fraction > silt fraction [∵ $I_p > 7\%$]

(ii) GM ⇒ silty gravel

% fineness > 12 and $I_p < 4\%$

silt fraction > clay fraction [∵ $I_p > 4\%$]



Sand:-

(i) SC ⇒ clayey sand

$\%$ fineness > 12 and $I_p > 7\%$

clay fraction > silt fraction [$\because I_p > 7\%$]

ii) SM ⇒ silty sand

$\%$ fineness > 12 and $I_p < 4\%$

silt fraction > clay fraction

Note:- If plasticity index is between $4\% - 7\%$ then dual symbols are ased.

Example:-1 From a particle-size distribution curve of a sandy soil, the following data is obtained:

Determine the uniformity coefficient & coefficient of curvature. Is this soil is well graded or poorly graded?

Size of particle (mm)	percentage finer
0.48	60
0.33	30
0.21	10

Solution:-

Given $D_{60} = 0.48\,mm$, $D_{30} = 0.33\,mm$ and $D_{10} = 0.21\,mm$

Coefficient of curvature, $C_u = \frac{D_{60}}{D_{10}}$

$$\Rightarrow \quad C_u = \frac{0.48}{0.21} = 2.28$$

and coefficient of curvature, $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

$$C_c = \frac{(0.33)^2}{0.48 \times 0.21} = 1.08$$

For well graded sand, $C_u > 6$ and $1 \le C_c \le 3$.

So it is a poorley graded sand.

Example:-2

Sieve sixe	4.75 mm	75 micron
% finer	80	7

For the above soil sample, the size of aggregates vary linearly and it is found that particles finer than 75 micron are non-plastic. According to Indian standard

(a) SP-SM (b) SW-SM

Solution:-

→ It is a coarse soil, as only 7% are finer than 75μ sieve. Also it is a sandy soil because more than 50% of the coarse fraction passes through 4.75 mm sieve.

Since size of aggregates varies linearly.

D_{60} : $$\frac{80-7}{4.75-0.075} = \frac{80-60}{4.75-D_{60}}$$

$$\Rightarrow D_{60} = 3.47\text{mm}$$

D_{30} : $$\frac{80-7}{4.75-0.075} = \frac{80-60}{4.75-D_{30}}$$

$$\Rightarrow D_{30} = 1.548\text{mm}$$

Similarly, $D_{10} = 0.267\text{mm}$

∴ $$C_u = \frac{D_{60}}{D_{10}} = 12.99 > 6$$

and $$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = 2.59$$

It mean, $1 \leq C_c \leq 3$

Thus soil is well graded, also the finer particles are non-plastic, so it is silt.

Hence option (b) is correct

Example:-3 Laboratory sieve analysis was carried out on a soil sample using a complete set of standard IS-sieves. Out of 500g of soil used in the test, 200g was retained on IS 600μ sieve, 250g was retained on IS 500μ sieve and the remaining 50g was retaining on IS 425μ sieve. Find the coefficient of uniformity. Also classify the soil.

Solution:-

S.N.	Sieve size	Weight retained (g)	cum-weight retaining (g)	cum. % retained	% finer %N
1.	600μ	200	200	40	60
2.	500μ	250	450	90	10
3.	425μ	50	500	100	0

∴ $D_{60} = 600\mu$ and $D_{10} = 500\mu$

$$\Rightarrow \quad C_u = \frac{600\mu}{500\mu} = 1.2$$

More than 50% of the soil pass through 600μ sieve, it means that greater percentage of the soil will pass through 4.75mm sieve. Hence the soil is definitely sandy soil.

For well graded sand

$C_u > 6$ and $1 \leq C_c \leq 3$

Here, $C_u = 1.2$ thus the soil is poorly graded sand.

Example:- 4 Classify the soil for data given:

Sieve size (mm)	Weight retained (g)
4.75	20
0.075	730

1000 g of soil was used

Liquid limit = 40%

plastic limit = 18%

the soil classification is

(a) GM (B) SM

(C) GC (D) ML-MI

Ans. (a)

S.N.	Sieve size (mm)	Weight retained (g)	cum-weight retained	cum % retained	% finer %N
1.	4.75	20	20	2	98
2.	0.075	730	750	75	25

Since 98% of soil pass through 4.75mm IS sieve, and 75% are retained on 75μ, given soil is sand.

Also, 25% of soil is pass through 0.75mm sieve.

∴ fineness = 25%

$W_L = 40\%$, $W_P = 18\%$

$I_P = 22\% > 7\%$

∴ Here fineness > 12% and $I_P > 7\%$

∴ soil is clayey sand (SC).

* Classification of fine Grained soil:-

→ In ISSCS, fine Grained soils are classified on the basis of plasticity chart(I_p) and compressibility (W_L).

→ Generally soils are considered as fine soils, when 50% or more of the total Material by weight pass 75μ sieve.

→ LL(W_L) and PL(W_p) are determined for 425μ sieve fraction and corresponding plasticity index is fine out.

$$I_p = W_L - W_p$$

Case-1:- low plastic soil (Low compressibility)(LL< 35%)

CL → Low plastic inorganic clay

ML → low plastic silt.

OL → Low plastic organic clay

Case-2:- Medium plastic soil (Medium compressibility)(35% < LL < 50%)

CI → Medium plastic inorganic clay

MI → Medium plastic silt.

OI → Medium plastic organic clay.

Case-3:- Highly plastic soils (High compressibility) LL > 50%

CH → High plastic inorganic clay

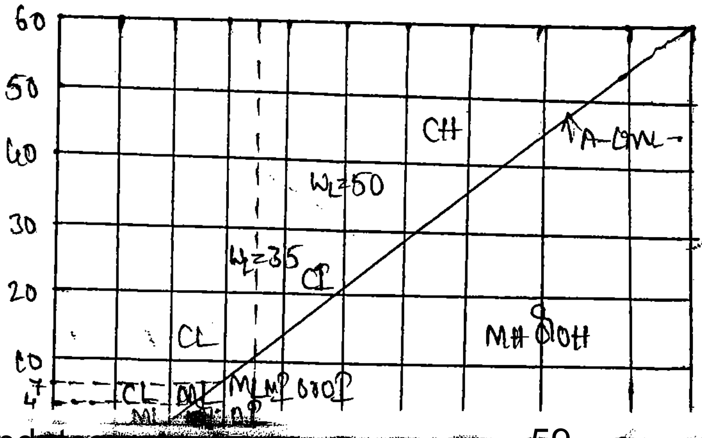
MH → High plastic silt.

OH → High plastic organic

Note:- Organic and inorganic soils are plotted in same zone in plasticity chart which are distinguished by odour and colour or liquid limit test on oven dry sample. If LL of oven dry is sample less than the three-fourth of in-site soil sample then soil is organic otherwise inorganic.

On x-axis :- liquid limit, W_L

Y-axis :- plasticity index, I_p



→ the above soil classification is based on a line called A-line, which is a boundary representing relationship between plasticity Index (I_p) and LL (w_L).

→ If I_p of soil > I_p of A-line.

the soil will lie above A-line and it will be inorganic clay (C)

→ If I_p of soil < I_p of A-line.

the soil will lie below A-line and it may be either silt (M) or organic clay (O)

→ the I_p of A-line is given by

$$I_p = 0.73(w_L - 20)$$

where w_L = liquid limit.

→ U-line represent upper boundary beyond which no soil lie. If results are found above U-line then test must be repeated.

$$I_p \text{ of U-line} = 0.9(w_L - 8)$$

where w_L = liquid limit.

→ Highly organic soils (eg. peat) are classified as Pt.

Example:-1 As per the Indian standard soil classification system, a soil sample of silty clay with liquid limit 40% and plasticity of 28% is classified as.

(a) CP (b) CI

(c) CL (d) CL-ML

Solution:- I_p of soil = 28%

I_p of A-line $= 0.73(w_L - 20)$

$= 0.73(40 - 28)$

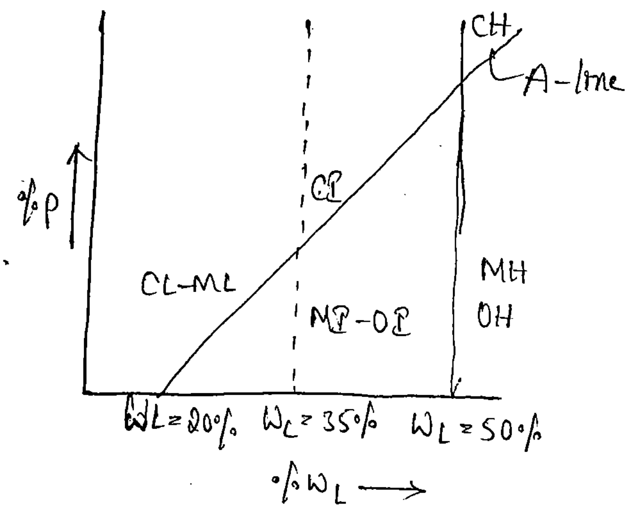
$= 8.76$

I_p of a soil > I_p of A-line.

∴ It will lie above A-line.

Also $35 < w_L < 50$

So soil is CI.



Examples 2 A soil has following properties,

LL = 40%, PL = 30%

% passing through 4.75 mm sieve = 65%

% passing through 75 μ sieve = 58%

(a) SC (b) CL

(c) ML (d) MH

Ans. (c)

Gravel fraction = % retained on 4.75 mm sieve = 35%

Coarse fraction = % retained on 75 μ sieve = 42%

Sand fraction = 65 − 58 = 7%

Since more than 50% soil pass through 75 μ sieve, soil is fine grained.

I_p of A-line = $0.73(W_L - 20)$

$I_{p,A} = 0.73(40-20) = 14.6\%$

I_p of a soil = $W_L - W_p = 40 - 30$

$I_p = 10\%$

$35 < W_L < 50$

∴ soil may be ML & OL

Example :- 3 A soil has following characteristics

% passing 75 μ sieve = 62%; liquid limit = 40%

plasticity index, I_p = 10%; liquid limit of oven dry sample = 25%

classify the soil according to ISSCS system.

(a) ML (b) OL

(c) CH (d) CL

Ans. (b)

More than 50% of soil pass through 75 μ sieve. So soil is fine grained.

I_p of A-line = $0.73(W_L - 20) = 0.73(40-20) = 14.6\%$

I_p of soil = 10%

I_p of soil < I_p of A-line. Hence soil will lie below A-line

Also, $35 < w_L < 50$, so may be MI & OI

Since liquid limit of oven dry soil is 25% which is less than $\frac{3}{4}$ of LL of soil.

therefore soil is OI (Medium plastic Organic clay).

Example:-4 A soil has following characteristics.

1. percentage of soil passing 75μ sieve = 20
2. percentage of fraction retained by 4.75mm sieve = 60
3. Liquid limit = 35
4. plastic limit = 20

Classify the given soil as per IS-soil classification system.

Solution:

% of soil retained on the 75μ sieve = 80

It is greater than 50% hence it is a coarse grained soil.

Since gravel fraction (i.e., 60%) is greater than 50, Hence large proportion of the coarse grained soil is gravel, the soil is gravel.

Fineness = % fraction which pass through 75μ sieve.

= 20% (which is greater than 12%)

In this case, soil is classified according to IS - plasticity chart.

$I_p = W_L - W_p = 35 - 20 = 15 > 7\%$

It means clay fraction > silt fraction

Hence the soil is classified as GC.

Example:-5 the following test results were obtained on a soil sample.

percentage passing through 4.75mm IS sieve = 98.5%

Percentage passing through 75μ IS sieve = 35%

$D_{60} = 0.22$ $D_{30} = 0.19$, $D_{10} = 0.16$

Liquid limit = 22%

plasticity limit = 19%

classify the soil by IS classification.

solutions:-

percentage of soil retained on the 75μ sieve = 65

It is greater than 50%. Hence it is a coarse grained soil.

since gravel fraction (i.e. 1.5%) is less than 50, large proportion of the coarse grained.

soil is sand

fineness = % fraction which pass through 75μ sieve.

= 35%

It means fines is greater than 12%.

In this case, soil is classified as per IS-classification

$$I_p = W_L - W_p = 22 - 19 = 3\%$$

which is less than 4%.

It means silt fraction > clay fraction.

Also,

coefficient of uniformity, $C_u = \frac{D_{60}}{D_{10}} = \frac{0.22}{0.16} = 1.38 < 6.$

and coefficient of curvature, $C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{(0.19)^2}{0.22 \times 0.16} = 1.03$

For the soil to be well graded,

$C_u > 6$ and $1 < C_c < 3$

Hence the given soil is classified as poorly graded silty sand i.e. SM.

Summary:-

→ Broadly soils are classified as coarse grained (cohesionless) and fine grained (cohesive) soils.

→ Gravel and sand are put in the category of coarse soil whereas silt and clays are put in the category of fine soils.

→ Generally soil classification is done on the basis of two criteria, viz.

(a) Grain size distribution

(b) plasticity of soil.

→ The Indian soil classification system is basically the same as the unified soil classification system but for a slight modification in the plasticity chart.

→ For classification of the soils, organic and inorganic soils are plotted in same zone in plasticity chart, which are distinguished by odour, colour & liquid limit on oven dry sample. If LL of oven dry sample is less then of three fourth of in-situ soil sample, then soil is called organic soil, otherwise inorganic.